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A novel management-based system of payments for ecosystem services for targeted agri-environmental policy

T. Rodríguez-Ortega[a,c,*], A.M. Olaizola[b,c], A. Bernués[a,c]

[a] *Centro de Investigación y Tecnología Agroalimentaria de Aragón (CITA), Zaragoza, Spain*
[b] *Departamento de Ciencias Agrarias y del Medio Natural, Universidad de Zaragoza, Zaragoza, Spain*
[c] *Instituto Agroalimentario de Aragón – IA2 – (CITA-Universidad de Zaragoza), Zaragoza, Spain*

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ABSTRACT

Agricultural policy should recognize the farmers' role in delivering ecosystem services (ES) to society, for which both farmers and policy makers need improved tools to set objective environmental targets and fair distribution of subsidies. We aimed to quantify the effect of beneficial agricultural practices on ES delivery, and to develop and apply a generic framework of management-based payments for ES (PES). We carried out a Delphi expert consultation (researchers and technicians/managers) on the interface agriculture-environment by which we measured the contribution of current agricultural practices at farm level to relevant ES in Mediterranean agroecosystems. Next, we designed a novel framework of PES that used these contributions to rank the practices that satisfied three agri-environmental policy objectives (equal importance of ES, focus on biodiversity and climate, and focus on social demands). We found that the relative contribution of practices to individual ES delivery was rather similar, especially for those ES influenced by many agricultural practices. However, when considering different objectives in the PES framework, differences in practice prioritization were apparent. The framework was able to reward farmers according to their objective contribution to conservation priorities. The PES system also showed that grazing management practices were multifunctional and delivered ES in bundles.

1. Introduction

Agriculture is a multifunctional activity since it does not only provide commodity outputs (food and fiber production), but also additional functions such as socio-economic viability of rural areas, food security, animal welfare and environmental outcomes (OECD, 2001; Renting et al., 2009). Among the positive environmental outcomes, ecosystem services (ES) focuses on the linkages between ecosystems, including agroecosystems, and human well-being (MEA, 2005). The ES framework invites to assess and explore further the multifunctionality of agroecosystems and stimulates debate about the need to introduce deep changes in the way agricultural policies are designed (EC, 2011), as well as has the potential to integrate provisioning and non-provisioning services at the same level of priority (Rodríguez-Ortega et al., 2014).

Currently, a wide range of farming systems with different degrees of specialization, integration and intensification of production coexist across the world (Bouwman et al., 2005). Depending on management practices, these systems can be a source of numerous disservices or, conversely, of multiple ES (Power, 2010); in turn, both ES and disservices affect agricultural productivity (Dale and Polasky, 2007), especially at large temporal scales. In general, low-input farming systems, such as pasture-based livestock systems or integrated mixed farming systems, are associated with a larger number of beneficial agricultural practices providing a great range of ES, compared to intensive farming systems (Cooper et al., 2009). Examples of these ES provided by low intensity farming across Europe are the preservation of agricultural landscapes, farmland biodiversity, water quality and availability, soil functionality, climate stability (related to carbon storage and greenhouse gas emissions), resilience to flooding and fire, or air quality. However, most of these ES exhibit the characteristics of public goods, so conventional markets are often not the best institutional frameworks to manage them (Costanza et al., 2014) and thus farmers have little incentives to provide them. One way to solve this is to economically recognize the ES delivery by farmers' activity and compensate them accordingly to the provision of ES, for example by shifting the emphasis of agricultural policies and public money towards the supply of ES demanded by society.

Farmers and farming communities may be seen as modulators of ecosystem functioning that build a humanized (agro)ecosystem, where

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[*] Corresponding author.
E-mail address: trodriguezo@cita.aragon.es (T. Rodríguez-Ortega).

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they have a significant role to play in the preservation and conservation of resources and in providing ES (or ecosystem disservices) in multiple ways depending on their farm management. To ensure the engagement of farmers in conservation through the sustainable use of resources and the delivery of ES, farmers and policy makers need a way to connect agricultural management with the provision of ES. Despite the incomplete scientific understanding of the complex causal relationships between management actions, biophysical processes and ES delivery (Rodríguez-Ortega et al., 2014), there is information and knowledge to better design agri-environmental policies, and we cannot wait for certainty and precision of methods to act (Farley and Costanza, 2010). Payments for ecosystem services (PES) applied to farming can offer an alternative way to achieve conservation objectives (Engel et al., 2008).

The ES framework has gained increasing attention from the research community and recently reached the political agenda. However, some authors conclude that in terms of policy design the ES framework is currently a “buzz approach”, which nobody really knows how to use (Matzdorf and Meyer, 2014). PES can be defined as “a *voluntary* transaction where a *well-defined ES* (or a land use likely to secure that service) is being ‘bought’ by a (minimum one) *ES buyer* from a (minimum one) *ES provider* if and only if the ES provider secures ES provision (*conditionality*)” (Wunder, 2005). However, only few existing PES fit the narrow Wunder’s definition, as reviewed by Sattler and Matzdorf (2013), while the majority of approaches rather fit the broader PES concept (definition of Muradian et al., 2010), which also includes incentives or public subsidies defined by regulatory means. Wunder (2015) also defends PES as a functional tool, rather than normative prescriptions of desirable outcomes, such as poverty or justice. He also recognizes that a sophisticated design (payment differentiation and spatial targeting) and adequate implementation (compliance monitoring and sanctioning) are desirable but too costly (transaction cost), so that they are only partially applied in practice (Wunder et al., 2018).

Payment mode can be oriented twofold: by the outcome ES or by the land management that secure that ES. Both approaches have advantages and disadvantages. On the one hand, result-based PES are desirable because they theoretically reward environmental outcomes objectively; however, they implicate a higher risk for the provider (farmers, in our case) because the ES generation is complex and not all influencing factors (such as weather) are under the control of farmers (Reed et al., 2014). Additionally, while the payment should be for the farmer that provide the ES, ES may be delivered at different scales (Hein et al., 2006), some of them higher than the farm, and need to be measured at the appropriate resolution (Dale and Polasky, 2007), which place conflicts with other farmers’ management. Also, ES measurement can add further to the transaction costs of the schemes (Farley and Costanza, 2010). On the other hand, management-based PES are seen as less effective, as the link between land management and ES can be rather weak and might be based on assumptions that are not always backed up by scientific evidence (Reed et al., 2014). Nevertheless, considering the multiple interrelations between ES flows, management payments may be the preferred solution, as they can deliver ES in bundles, avoiding the commodification of single ES (Kosoy and Corbera, 2010).

PES are historically much more frequent in developing countries, mostly in Latin America (Schomers and Matzdorf, 2013). Few authors have made the efforts of reviewing the different PES mechanisms. One of the most comprehensive assessment was done by Sattler et al. (2013), who collected from the literature 32 characteristics, grouped in 10 categories, with multiple specifications to explain the variety of PES approaches. They indicated that characteristics such as intermediaries, involvement of governmental actors, contract length, co-benefits, voluntariness in agreements and design of PES as output-based schemes are of particular importance for the success of PES. However, result-based PES should be restricted to cases where causal relationships are well established and can be represented by simple indicators (Uthes and Matzdorf, 2013), which is not the case in agriculture where interrelationships between practices and multiple ES are fairly complex, not well-studied yet and expressed with a wide range of indicators (Rodríguez-Ortega et al., 2014).

Thus, some authors have developed studies to assess effects of land management on ES (van Oudenhoven et al., 2012), to design indicator-based agri-environmental payments to cover landscape public goods (Hasund, 2013), to study key farm management practices of high conservation relevance (Ribeiro et al., 2016), etc. Although the importance of land management is acknowledged in the descriptions of all the existing PES, agricultural management is not explicitly included and linked to the objective provision of ES. In this sense, a better understanding of the processes by which management regimes influence trade-offs and synergies among ES is critical to choose the most beneficial agricultural practices that would allow the outputs of a range of ES to be envisioned (Dale and Polasky, 2007; Power, 2010). It would also address a greater integration between agri-environmental schemes to attain a wider and more efficient delivery of ES for society (Reed et al., 2014). However, to our knowledge, there are no generic frameworks that link agricultural practices with multiple ES delivery.

The aims of this study were: i) to quantify the effect of beneficial agricultural practices on ES delivery, ii) to develop and apply a generic framework of management-based payments for ES, and iii) to apply this PES framework to diverse policy settings that represent different combinations of ES.

2. Materials and methods

We valued the contribution of agricultural practices to relevant ES in Mediterranean agroecosystems through an expert-based assessment embedded in the PES framework. Below, we explain in three sections how we: i) selected the relevant agroecosystems, identified the ecosystem services linked to mixed sheep-crop farming systems and the agricultural practices carried out by these systems; ii) estimated the contribution of these practices to the relevant ES; and iii) designed and applied the PES framework.

2.1. Selection of agroecosystems, ecosystem services and agricultural practices

We set our study in north-east Spain (Aragón region), due to its heterogeneous environmental characteristics that gives rise to a wide variety of farming systems, in particular mixed sheep-crop systems (Barrantes et al., 2009; Olaizola et al., 2015). Overall, these farming systems are located in two dominant Mediterranean agroecosystems: i) mountain areas, with traditional self-sufficient systems characterized by extensive, low-input/low-output farming (Asensio and Casasús, 2004) and with little use of arable land and large dependency on natural pastures; and ii) semi-arid lowlands, with systems that followed a path of intensification, linking sheep to the most developed agriculture with irrigated lands and a higher use of off-farm feed inputs (Olaizola et al., 1995).

Due to the focus of our study, we only considered non-provisioning ES, which do not normally have market price (de Groot et al., 2012). The five ES under consideration were: maintenance of sustainable agricultural landscapes (cultural ES), biodiversity conservation (supporting ES), forest wildfires prevention (regulating ES), regulation of climate change through the carbon sequestration (regulating ES), and production of local quality products (quality regards more cultural ES than provisioning ES). These ES are among the most relevant non-market functions of European agriculture (Cooper et al., 2009) and have been identified from a biophysical point of view in pasture-based livestock systems by the scientific community (Rodríguez-Ortega et al., 2014). Additionally, they were confirmed in previous socio-cultural studies using focus groups with citizens and farmers (Bernués et al., 2016).

Agricultural practices that provide particular environmental benefits to ES were extracted from the report of Cooper et al. (2009), which is based on a number of sources such as literature review, agri-environment schemes and experts assessments in European regions. To focus on those specific practices that apply to our Mediterranean agroecosystems, we monitored 10 representative sheep-crop farms (five per agroecosystem). These farms were selected from previous typologies (Rodríguez-Ortega et al., 2017), therefore, they constituted "typical" farms, i.e. modal representations of their corresponding farming systems (Feuz and Skold, 1992). First, we collected data on the structure of farms including: agricultural and pasture area (size, number of plots, water regime, land use, species and varieties, productivity, rotations, etc.); traditional elements (terraces, stone walls, paths, drove roads, hedgerows, scattered trees, etc.); origin of resources (water, energy and materials); flock details (species, size, management of batches, genetic improvement, feeding, waste management, etc.); destination of products (self-sufficiency, commercialization); and equipment (machinery and infrastructure). Then, we monitored the farms (once every 2–3 months) during an agronomic year (2014–2015) to collect detailed data on the management of semi-natural vegetation (cleaning, pruning), croplands (inputs such as seeds, manure, inorganic fertilizers, pesticides, water, etc.), animals (veterinary treatments), machinery use for all practices (tilling, fertilizing, harvesting, etc.), grazing calendar (type and area of pasture, time spent in pasture, distance from the stable, shepherding method, etc.), in-door rations (amounts, origin of feed, etc.), harvests, self-consumption and exchanges of products, work done for third parties, hired labor and machinery, etc.

Finally, from the 66 agricultural practices with potential contribution to deliver public goods in Europe (Cooper et al., 2009), we selected the ones (n = 36) that were carried out in these typical farms. Table 1 includes these practices grouped by farm management domains (semi-natural vegetation and landscape elements, croplands, inputs, and grazing and silviculture activities). The contribution of the 36 agricultural practices to the five ES under consideration is explained in the next section.

2.2. Expert-based assessment of agricultural practices contribution to ES

We carried out an expert consultation with an on-line Delphi panel, valuing the contribution of the several agricultural practices to relevant ES in Mediterranean agroecosystems. The Delphi method consists of an iterative consultation process of many 'informed' individuals in different disciplines or specialties to contribute, with information or judgements, to knowledge accumulation until a certain degree of judgement convergence is attained. The technique has been successfully applied within the domain of ecosystem services (Scolozzi et al., 2012).

2.2.1. Selection of experts

The experts were chosen covering different types of knowledge and backgrounds: i) researchers on agriculture-environment relationships and ii) technicians/managers from the government and Non-Governmental Organizations related to agriculture and environmental conservation, as well as from agricultural associations, local agribusiness and cooperatives in the area of study. With these groups we intended to contrast the theoretical and objective knowledge with the applied knowledge. We contacted, by an invitation e-mail, 85 researchers and 165 technicians/managers, of which 33 and 48, respectively, accepted to participate in the study. Finally, 29 researchers and 32 technicians/managers completed the process, fulfilling the minimum number of experts by category (Okoli and Pawlowski, 2004).

2.2.2. Design of questionnaires to experts and data collection

The Delphi survey involved two rounds of deliberation since only 50% of experts changed one or few responses in the second round. Most Delphi researchers agree that there is very little benefit in conducting more than three rounds (Murphy et al., 2002), being the most frequent to conduct two or three (Wentholt et al., 2009). We guaranteed anonymity along the process of data collection and presentation of results.

The first round, hold at the end of 2015, implied an on-line questionnaire with three parts. First, we included a brief illustrated description of the Mediterranean mountain and semiarid lowland agroecosystems under study. Second, we collected professional data and asked experts to make a self-appraisal on their knowledge about each ES according to a five-point Likert scale (1: very low, 2: low, 3: intermediate, 4: high, 5: very high knowledge). In the third part, respondents had to rate the beneficial contribution of each agricultural practice to the five ES separately, according to a six-point Likert type scale (0: none, 1: very low, 2: low, 3: intermediate, 4: high, 5: very high contribution). We also included the "don't know" option. An open box for comments and suggestions was also provided per ES. We presented the practices randomly to experts and asked them to quote, for each ES, only those interactions (marked with an X in Table 1) that were relevant according to Cooper et al. (2009). The second round, hold at the beginning of 2016, was carried out sending the global average scores and the original responses given in the first round. Global responses were presented numerically and graphically with a frequency distribution of the different degrees of contribution of agricultural practices to each ES. Individual responses were given as the original Likert-type scale. We asked experts to rethink their individual responses compared to the global responses and to make modifications if appropriate.

2.2.3. Data analysis

Since Likert scale can be a summative scale, we calculated the contribution of each agricultural practice to a given ES (C_{ES}) as the sum of the experts' scores (j) for that agricultural practice (i) divided by the total score for all agricultural practices for that ES. We considered the number of experts that answered "don't know" to neutralize the effect of zero values on scores. Then, we multiplied by 100 to obtain a percentage as indicated in the equation:

$$C_{\mathrm{ES}}(\%) = \frac{\sum_{j=1}^{J} Cij}{\sum_{i=1}^{I} \sum_{j=1}^{J} Cij} \cdot 100$$

We presented results corrected by the self-appraisal by multiplying scores by 0.2: very low, 0.4: low, 0.6: intermediate, 0.8: high and 1: very high knowledge. Knowledge of expert categories (researchers vs. technician/managers) on ES and the contribution of agricultural practices to ES across expert categories were analyzed for differences with statistical significance using a Kruskal-Wallis test.

2.3. Payment for ecosystem services (PES) framework

We aimed at designing a generic and sound framework that links beneficial agricultural practices at farm level with the provision of single or multiple ES, using the information collected in the previous section. We assumed that the valuations of the experts reflected the effect of agricultural management on ecosystem properties and functions and of these on ES, providing a unique and comparable unit of measurement (Rodríguez-Ortega et al., 2014). Such a framework constitutes a management-based PES with the potential to establish objective relationships between agricultural practices and ES delivery. In contrast to results-based PES, the consideration of real farm management makes possible to identify a wide range of agricultural practices, with multiple interrelated effects, to address synergies among ES that would allow the outputs of multiple ES to be envisioned (Power, 2010). The final objective of our PES system was to measure objectively the contribution of individual farmers to the provision of ES.

Considering that ES is a human-centered concept (MEA, 2005), we also aimed at addressing different actors' demands (farmers, researchers, society, policy makers) by allowing to customize the agricultural practices and the environmental targets. This characteristic

Table 1
Agricultural practices and ES evaluated. Modified from Cooper et al. (2009).

Groups	Agricultural practices	Ecosystem services				
		Landscape	Biodiversity conservation	Forest wildfires	Carbon sequestration	Quality products
Vegetation and elements	1. Maintaining semi-natural vegetation (trees and shrubs) characteristic of each area	X	X	X	X	X
	2. Maintaining grasslands	X	X	X	X	X
	3. Managing land in small plots	X	X	X		
	4. Retention of hedges, shrubs and trees among arable fields	X	X	X	X	
	5. Retention terraces	X	X		X	
	6. Retention traditional buildings and field boundaries	X	X			
	7. Retention of water points	X	X	X		
	8. Retention of drove roads and tracks	X	X	X		
Crops and species	9. Crop diversification	X	X		X	
	10. Growing locally adapted crop varieties and breeds	X	X		X	X
	11. Growing crop varieties with lower requirements	X	X		X	X
	12. Genetic selection for high productivity		X			X
	13. Retention of high proportion of semi-natural meadows and pluri-annual crops	X	X		X	
	14. Utilizing nectar source crops for pollinators	X	X			
	15. Utilizing cover crops	X	X		X	
	16. Utilizing crop rotations, including legumes	X	X		X	X
	17. Maintaining fallows in rotation	X	X	X	X	
	18. Substituting bare fallow for green/seeding fallow	X	X		X	
Inputs	19. Reducing use of machinery	X	X	X	X	
	20. Reducing ploughing/tilling				X	
	21. Reducing chemical fertilizers		X		X	X
	22. Utilizing manure correctly	X	X		X	X
	23. Reducing pesticide use		X			X
	24. Reducing herbicide use	X				
	25. Reducing animal drugs		X			X
	26. Reducing proportion of animal concentrates		X		X	X
	27. Reducing off-farm dependency	X	X		X	X
Grazing and silviculture	28. Extend grazing period	X	X	X	X	X
	29. Grazing in semi-natural habitats	X	X	X	X	X
	30. Grazing in remote and abandoned areas	X	X	X	X	
	31. Grazing with several species	X	X	X	X	
	32. Moving herds seasonally	X	X	X	X	X
	33. Maintaining meadow mowing	X	X	X	X	
	34. Carcasses left in situ		X			
	35. Adapting stocking rate to the carrying capacity of agro-ecosystem	X	X	X	X	
	36. Active management of forest (forestry/silviculture)	X	X	X	X	X
Total		29	34	16	26	16

gives versatility to the framework, which can be adapted to other socio-ecological systems. Depending on the agroecosystem, users may define and quantify (e.g. with an expert-based assessment) new sets of agricultural practices that are beneficial for these agroecosystems. Users (e.g. policy makers) can also exclude some agricultural practices on the existing sets if needed (e.g. specialized farming systems), and even prioritize or exclude some ES from the policy objective, attending to political goals or conservation priorities of the territory.

2.3.1. PES application to Mediterranean agroecosystems

To operationalize and show the potential of the PES framework, we defined three policy scenarios in Mediterranean agroecosystems. Scenarios included different prioritizations of ES according to feasible targets of policymaking. **Scenario 1 – equal prioritization**: included the five ES under consideration with an equally importance of 20%, i.e. without any specific prioritization of ES. **Scenario 2 – biodiversity and climate**: considered two ES that are essential for human well-being and are much discussed due to their global implications (Farley et al., 2010). We assumed equal importance for the two ES (50%): biodiversity conservation and the potential of climate change mitigation through carbon sequestration in soils, since this is the major store of C within the biosphere (Powlson et al., 2011). **Scenario 3 – social demand**: considered the most relevant ES for society in the region according to previous studies (Bernués et al., 2014). The percentages of importance were 8.2% for conservation of the agricultural landscape, 18.4% for biodiversity conservation, 53.2% for the prevention of wildfires and 20.2% for the production of quality products linked to the territory. With the PES framework, we investigated which agricultural practices should be promoted to target the different policy objectives.

3. Results

3.1. Agricultural practices and ES in Mediterranean agroecosystems

3.1.1. Differences in expert knowledge

There were no differences on the stated knowledge of researchers and technicians/managers about ES (Fig. 1). The best known ES were landscape, biodiversity and quality products, while the worst known were forest wildfires and, specially, carbon sequestration. The lower knowledge about carbon sequestration probably transcended the quantification of particular agricultural practices, since the response rate was the lowest in both groups of experts and some of them expressed problems on establishing differences between practices that contributed to the “net” carbon sequestration and those that store

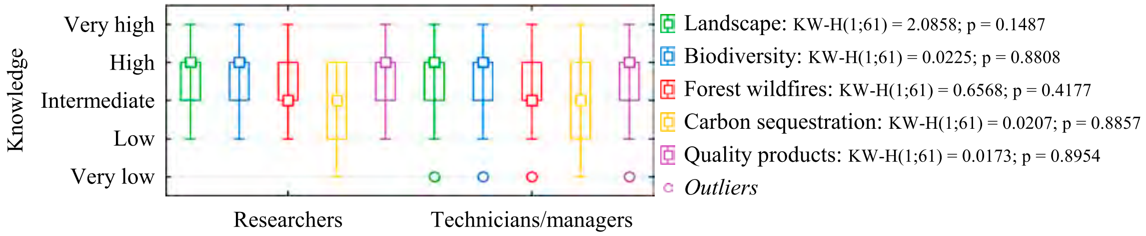
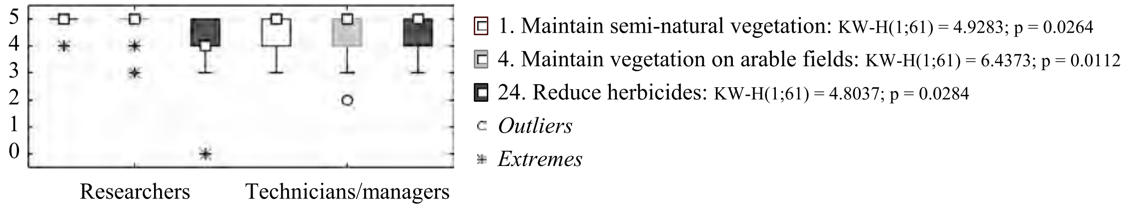


Fig. 1. Expert knowledge about ES. KW-H: Kruskal-Wallis H Test. Median; box: 25–75%.

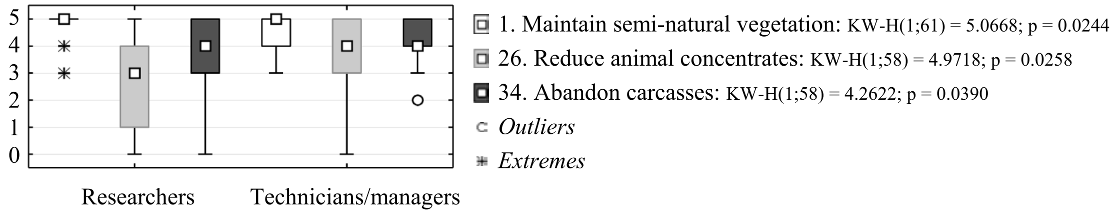
carbon (carbon sink).

Both expert categories also valued similarly the contributions of agricultural practices to ES, excepting those represented in Fig. 2. On the one hand, researchers valued higher the role of permanent vegetation (*semi-natural vegetation* on landscape, biodiversity and quality products; and *hedges, shrubs and trees among arable fields* on landscape). On the other hand, technicians/managers valued higher practices such as input consumption (*herbicides* on landscape; *animal concentrates* on biodiversity; *machinery use* and *ploughing/tilling* on carbon sequestration; and *animal drugs* on quality products) and the management of

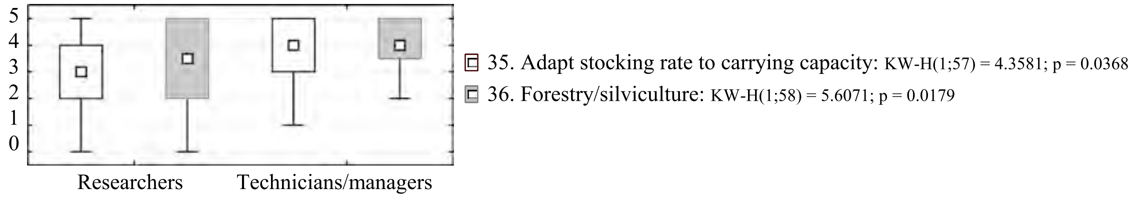
a) Maintenance of sustainable agricultural landscapes



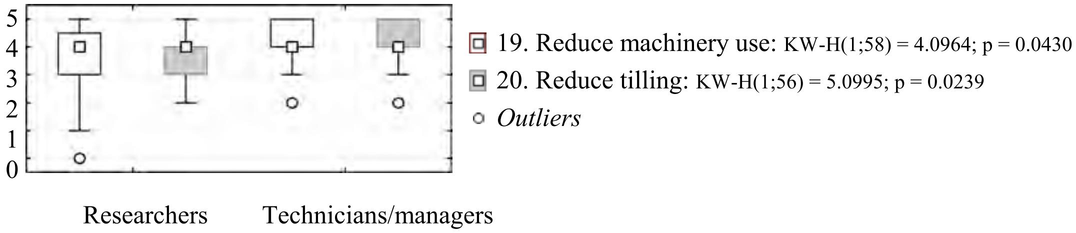
b) Biodiversity conservation



c) Forest wildfires prevention



d) Carbon sequestration



e) Production of local quality products

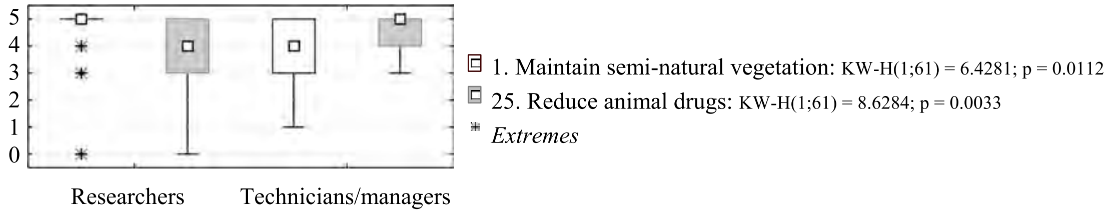


Fig. 2. Diffrences on expert valuation of agricultural practices contribution on landscape (a), biodiversity (b), forest wildfires (c), carbon sequestration (d) and quality products (e). Showed variables only with significance level $p \leq 0.05$. KW-H: Kruskal-Wallis H Test. Median; box: 25–75%

Table 2

Ranking of agricultural practices according to their contribution to the delivery of individual ES and multiple ES considering an scenario of equal prioritization of ES.

Agricultural practices	Individual ES					Multiple ES (equal prioritization)
	Landscape maintenance	Biodiversity conservation	Wildfires prevention	Carbon sequestration	Quality products	
32. Moving herds seasonally	3,83	3,28	7,02	3,51	7,55	*5,04*
2. Maintaining grasslands	3,80	3,33	6,59	4,32	6,42	*4,89*
36. Active management of forest (forestry/silviculture)	3,53	3,04	7,27	4,30	5,92	*4,81*
29. Grazing in semi-natural habitats	3,43	3,10	7,08	3,61	6,54	*4,75*
1. Maintaining semi-natural vegetation (trees and shrubs) characteristic of each area	3,86	3,48	5,73	4,44	6,06	*4,72*
28. Extend grazing period	3,06	2,65	6,72	3,41	5,85	*4,34*
10. Growing locally adapted crop varieties and breeds	3,71	3,25		3,76	7,77	*3,70*
22. Utilizing manure correctly	3,54	3,17		4,92	6,46	*3,62*
35. Adapting stocking rate to the carrying capacity of agro-ecosystem	3,96	3,46	6,28	4,32		*3,61*
30. Grazing in remote and abandoned areas	3,52	3,20	7,10	3,68		*3,50*
31. Grazing with several species	3,45	3,04	6,83	3,25		*3,32*
27. Reducing off-farm dependency	3,20	2,54		4,01	6,80	*3,31*
4. Retention of hedges, shrubs and trees among arable fields	3,86	3,33	4,82	4,29		*3,26*
33. Maintaining meadow mowing	3,31	2,89	6,50	3,22		*3,18*
11. Growing crop varieties with lower requirements	3,27	2,80		3,82	5,55	*3,09*
16. Utilizing crop rotations, including legumes	3,58	3,04		3,47	4,77	*2,97*
17. Maintaining fallows in rotation	3,36	2,74	5,31	3,36		*2,95*
19. Reducing use of machinery	2,91	2,69	4,45	4,08		*2,83*
21. Reducing chemical fertilizers		3,14		4,15	6,12	*2,68*
7. Retention of water points	3,75	3,31	6,34			*2,68*
8. Retention of drove roads and tracks	3,64	2,70	6,78			*2,62*
26. Reducing proportion of animal concentrates		2,38		3,85	6,75	*2,59*
3. Managing land in small plots	3,12	2,69	5,19			*2,20*
23. Reducing pesticide use		3,56			7,17	*2,15*
13. Retention of high proportion of semi-natural meadows and pluri-annual crops	3,46	2,96		4,10		*2,10*
25. Reducing animal drugs		3,07			6,71	*1,96*
15. Utilizing cover crops	3,04	2,70		3,90		*1,93*
5. Retention terraces	3,51	2,66		3,11		*1,86*
9. Crop diversification	3,09	2,87		3,25		*1,84*
18. Substituting bare fallow for green/seeding fallow	2,94	2,77		3,29		*1,80*
14. Utilizing nectar source crops for pollinators	3,27	3,23				*1,30*
6. Retention traditional buildings and field boundaries	3,43	2,49				*1,18*
12. Genetic selection for high productivity		1,29			3,56	*0,97*
20. Reducing ploughing/tilling				4,56		*0,91*
24. Reducing herbicide use	3,56					*0,71*
34. Carcasses left in situ		3,13				*0,63*
Total	100,00	100,00	100,00	100,00	100,00	*100,00*

Contribution (%)

Low Medium High

The contributions of agricultural practices to individual ES show the raw estimations of experts. These contributions are not comparable among ES because of the different number of practices within each ES. Conversely, the scenario of equal prioritization establishes the global relevance considering all practices, since it considers a 20% of importance for every ES.

grazing animals and silviculture (*carcasses left in situ* on biodiversity; and *stocking rates* and *forestry* on forest wildfires). In addition, some practices (*substituting bare fallow for green/seeding fallow*, *moving herds seasonally*, and *utilizing crop rotations*) probably were more difficult to be valued considering their low mean response rate across all ES (84%, 89% and 89%, respectively).

3.1.2. Contribution of agricultural practices to ES delivery

Agricultural practices may contribute to one or multiple ES delivery, regardless the ES targeted by policy (Table 2). There were agricultural practices important for single ES, such as *reducing pesticide use* for biodiversity conservation, *utilizing manure correctly* for the carbon sequestration, or *growing locally adapted crop varieties and breeds* for the production of local quality products. When considering several ES, other practices arose as more important because of their multifunctional role (e.g., *moving herds seasonally, maintaining grasslands*, *forestry/silviculture*, *grazing in semi-natural habitats*, *maintaining semi-natural vegetation*, etc.). Therefore, some ES, such as prevention of forest wildfires and provision of quality products, were influenced by specific practices; while other ES, such as conservation of landscape and

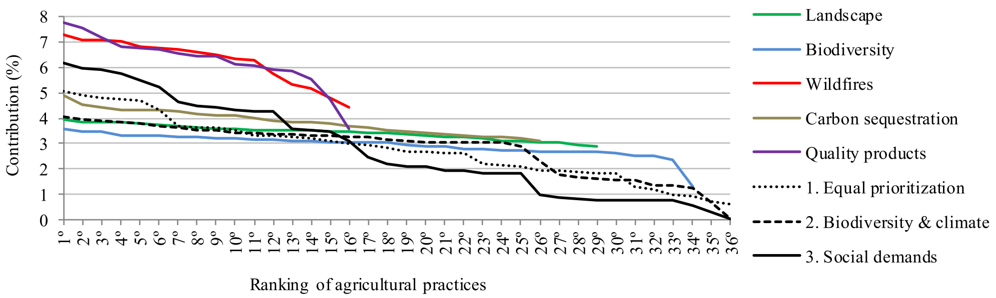


Fig. 3. Range of ranking of agricultural practices for individual ES and scenarios. Horizontal axis represents the ranking of agricultural practices (not the identifier number), i.e. the practices vary (for a particular ranking place) among ES and scenarios.

biodiversity, were delivered in bundles due to the synergies among agricultural practices.

The large number of practices influencing individual ES (e.g., landscape or biodiversity) diluted their relative contribution. Fig. 3 shows the additive contribution of agricultural practices to the individual ES in decreasing order. However, when several ES were targeted according to policy objectives (scenarios in Fig. 3), the synergies among practices highlighted the top agricultural practices.

Overall, when grouping practices in domains (Fig. 4), we can see that the practices related to *grazing and silviculture* were the most important for the delivery of multiple ES (in scenario 1), meaning that they have higher multifunctionality. This was also partly due to the great contribution to wildfires prevention (55%). The reduction of *inputs* was very important (40%) for the quality of products. For the rest of ES, the management domains had similar contribution (around 20–30%), with some exceptions, for example *inputs* for landscape (13%) or *vegetation and elements* for quality products (12%) and carbon sequestration (16%).

3.2. PES framework and application to Mediterranean agroecosystems

A management-based PES framework able to recognize the multifunctional role of agroecosystems must consider the multiple agricultural practices and ES involved, as we depict in Fig. 5. The links between agricultural practices at farm level and the provision of ES may be quantified according to expert knowledge, as in our study, or in alternative ways according to the type of agroecosystem and data available. The user can define and allocate the budget according to the policy priorities (combination of ES). For the PES framework to be effective in delivering the desired outcomes, there must be a system of monitoring in place. If needed, some of the agricultural practices can be customized, e.g., for specialized animal farming systems using natural pastures only, the cropping practices could be excluded. The PES framework is implemented in Excel and is fully operational.

The application of the PES framework to Mediterranean sheep-crop farming systems is illustrated in Fig. 6 for the two additional policy scenarios. Regarding the scenario targeting biodiversity and climate (scenario 2), the PES framework highlighted some agricultural practices such as *utilizing manure correctly*, *maintaining semi-natural vegetation*, and *adapting stocking rate* (each one ≈4% of contribution), although most of practices had similar contributions (≈3%). Practices grouped in domains also had similar importance (20–30%). For the scenario representing the social demands (scenario 3), a narrower number of agricultural practices with more differentiated contribution to each ES was highlighted, e.g., *moving herds*, *grazing in semi-natural habitats*, *forestry*, *maintaining grasslands*, etc. (≈6%). These practices belonged to the domains of *grazing and silviculture* (41.79%) and *vegetation and elements* (28.17%), mostly due to their contribution to the wildfire prevention, highly prioritized by society.

4. Discussion

4.1. Agricultural practices and ES

The contribution of agricultural practices to ES has been studied with heterogeneous methodologies and metrics, rendering results difficult to compare (Rodríguez-Ortega et al., 2014). When biophysical information is incomplete, expert-based assessments allow for the understanding of complex phenomena, which are much broader in scope than the knowledge that any single person possesses by himself (Curtis, 2004). However, the insufficient knowledge of experts for some ES highlights the need to further investigation, e.g., carbon sequestration still has unsolved questions such as the role that environmental conditions or management practices play in the average net change in soil organic carbon (Stockmann et al., 2013). Similarly, the contribution of some agricultural practices (e.g., *bare vs. green/seeding fallow*, *herds movements*, *crop rotations*) to ES also requires additional study.

The different awareness of experts was probably due to their different backgrounds and level of involvement in decision-making (Jónsson et al., 2016), although they agreed on most estimations. In any case, our assessment offers a first attempt to provide an overall overview of the contribution of agricultural practices to individual or

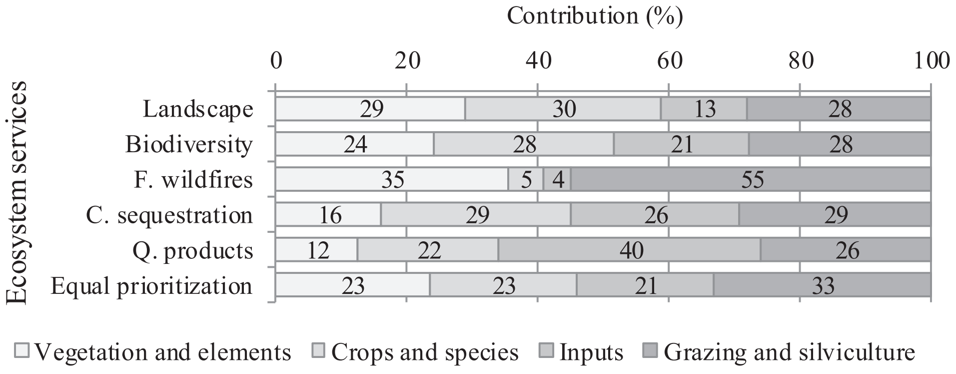


Fig. 4. Contribution of agricultural practices grouped in domains to the delivery of individual ES and multiple ES considering an scenario of equal prioritization of ES.

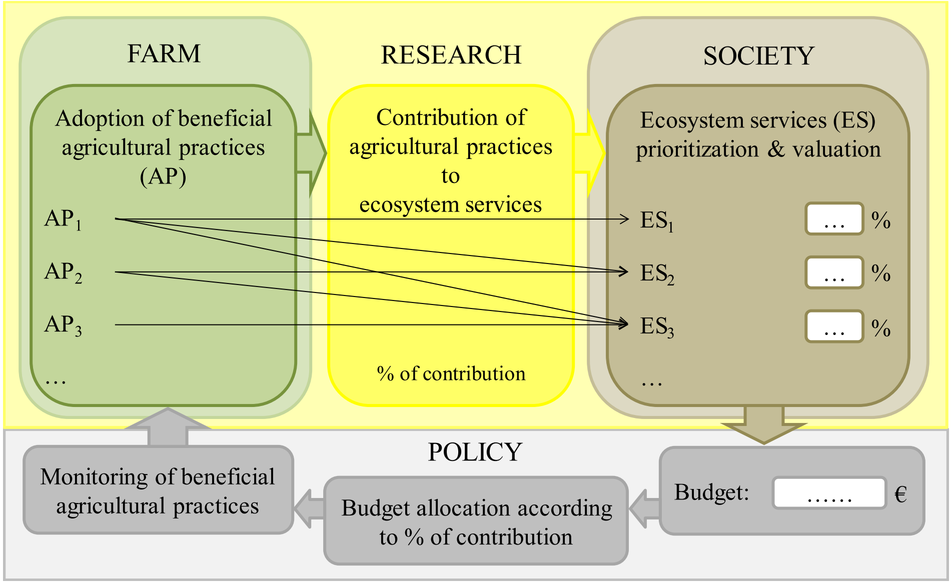


Fig. 5. PES framework.

multiple ES in Mediterranean agroecosystems, which can be improved with better information or extended to other agroecosystems.

We observed that there are many agricultural practices that influence ES delivery (Cooper et al., 2009) and the interrelationships between them are complex (Rodríguez-Ortega et al., 2014). Some practices, such as *leaving carcasses of dead animals in situ*, have a straightforward impact on biodiversity (scavengers) (Margalida et al., 2011); while other practices, such *reducing ploughing/tilling* to reduce carbon losses and increase carbon sequestration (Aguilera et al., 2013), require a previous understanding of the dynamics of plant and soil organic matter (Paustian et al., 2000; Post and Kwon, 2000). Other practices, such as the *reduction in the use of pesticides*, have direct effect on biodiversity, e.g. decline of bumblebees (Le Féon et al., 2010), but also may have indirect effects such as decreasing eggshell thickness of non-targeted species (Bright et al., 2008). These agricultural practices are important when these single ES are the target.

However, providing multiple ES would require promoting more multifunctional practices that provide ES in bundles such as landscape and biodiversity (Tscharntke et al., 2005). For example, *adapting stocking rate to the carrying capacity of the agroecosystem* has a great influence on vegetation structure and composition (Sebastia et al., 2008), some of the main determinants of the landscape quality (Gómez-Limón and de Lucio Fernández, 1999); and on the creation and maintenance of sward structural heterogeneity (Tichit et al., 2005), the main mechanism by which grazing livestock affect biodiversity in pastures (Rook and Tallowin, 2003).

The agricultural practices included in this work show the multiple ways that farmers have to improve ES delivery in farming systems, modifying the "natural" flow of ES from nature towards people (Plantureux et al., 2016). Some authors (van Vliet et al., 2015) indicate that farmers' characteristics (motivation, attitudes, age, etc.) influence land use change in Europe. More generally, Fischer et al. (2012) argued that the current decoupling of the social and ecological subsystems is breaking the links between nature and society and, therefore, farmers do not have a clear incentive to maintain the environment and their associated ES. Although some authors maintain that PES are artificial tools that are not good enough to recover an inherent farmer motivation, they could be a useful strategy for ES conservation.

4.2. Reorienting the agri-environmental policies towards PES systems

The ES concept has yet to be mainstreamed into everyday management and decision making, such as in landscape planning (de Groot et al., 2010) or agricultural policy. The growing concern for nature conservation has fueled agri-environmental schemes in order to encourage farmers to improve their land management. However, the implementation of agri-environmental schemes heavily relies on common sense models, characterized by weak formulations that have no clear scientific evidence, but rather reflect general perceptions of how environmental outcomes are linked to interventions (Primdahl et al., 2010). Traditional voluntary agri-environmental schemes have been widely criticized for their low efficiency and effectiveness to improve nature conservation (Barreiro-Hurlé, 2016). While biodiversity improvements in response to changes in agricultural practices under agri-environmental programs have been detected, some studies have shown mixed or limited benefits, and even negative biodiversity outcomes (Ansell et al., 2016).

In order to make the concept of ES operational and useful for land management, we designed a PES system that can be implemented in current agri-environmental policy design. It looks into the links between a large number of agricultural practices at farm level, which are usually the target of agri-environmental schemes, and the provision of a wide range of ES. We illustrated a way to measure how agricultural practices should change to enhance the provision of multiple ES, according to varied policy objectives. It has been strongly emphasized that the ideal PES system would be a result-based PES, where the payments relate to the achievement of a defined environmental result and the farmer is allowed the flexibility to choose the most appropriate management to achieve that result (Keenleyside et al., 2014). However, choosing a result-based PES system will not by itself address all the weaknesses of management-based PES such as spatial targeting, payment differentiation and monitoring (Moxey and White, 2014). Result-based PES may introduce insecurity for farmers since the ES outcome may occur at multiple scales, often higher than the farm (Rodríguez-Ortega et al., 2014). Some authors argue that result-based PES should be restricted to cases where causal relationships are well established and can be represented by simple indicators (Uthes and Matzdorf, 2013). These issues, become more complicated if the objective is providing ES in bundles, which ultimately increases the benefits (Kemkes et al., 2010). Our framework could be considered as a transitional framework towards result-based PES, able to facilitate policy prioritization of ES at the global level with decisions made at the local level (Farley and Costanza, 2010), guiding farmers from a more familiar perspective such as their own land management. It also contributes to a

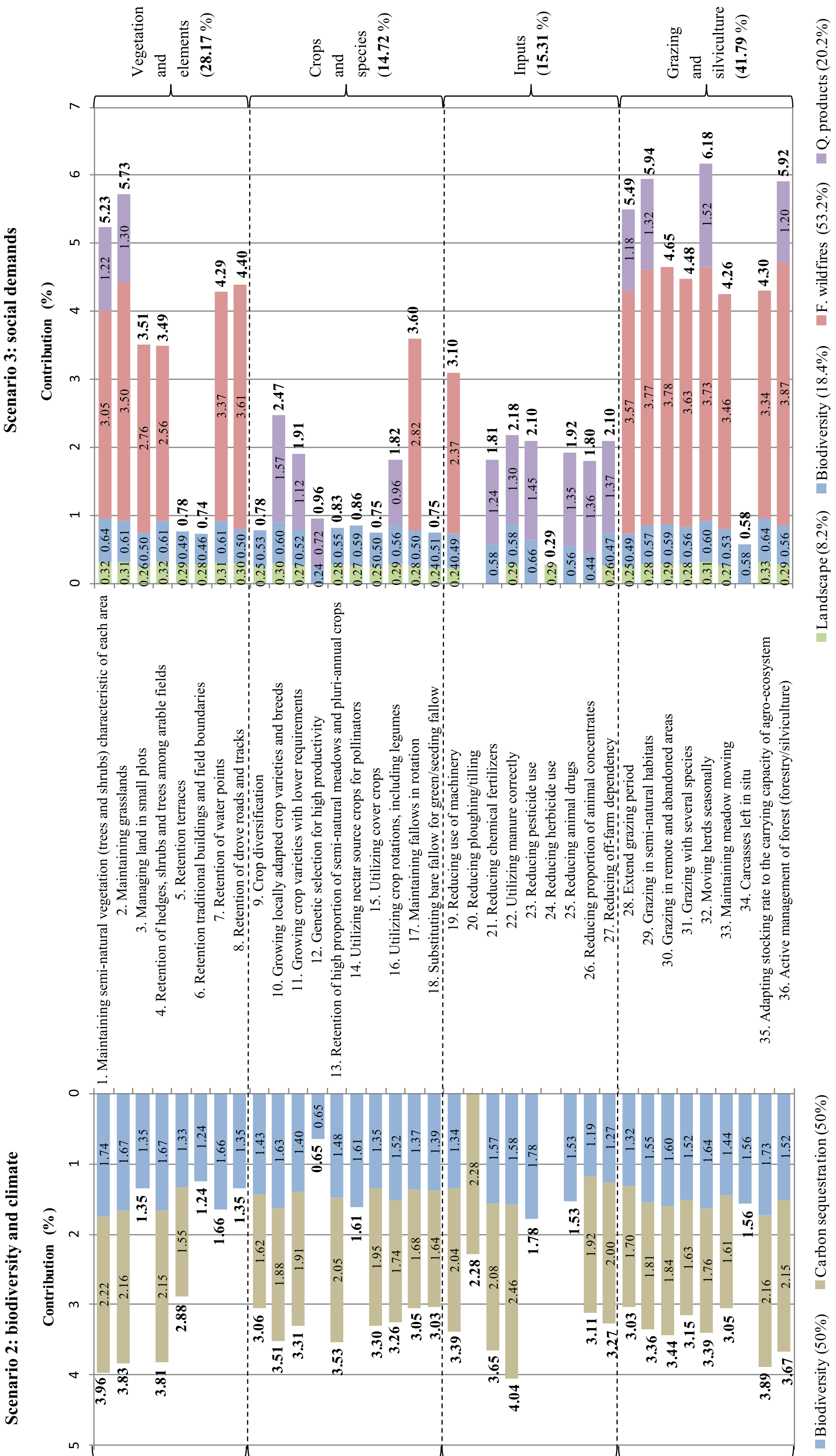


Fig. 6. Contribution of agricultural practices to ES in Mediterranean agro-ecosystems according to two scenarios: biodiversity and conservation, and social demands for ES.

reconfiguration of the roles of public bodies and communities that become core intermediaries or 'buyers' (Vatn, 2010), and uses multi-level governance solutions to link providers and beneficiaries of different 'catchments' (Paavola, 2016), as in agroecosystems. Our approach enables operationalizing the social–ecological systems framework for service-based management in multifunctional agroecosystems (Lescourret et al., 2015).

Mediterranean agroecosystems in Spain are backed up by the largest agricultural support system worldwide, the European common agricultural policy (CAP) (Plieninger et al., 2012). It currently contemplates "greening" measures (30% of the direct payments included in CAP Pillar 1) and agri-environmental schemes (included in Pillar 2 - Rural Development Policy). Despite both approaches reward farmers for voluntary environmental improvement, they assume the positive effects without determining the real contribution, i.e., they do not incorporate mechanisms to relate agricultural management with the targeted ES and, therefore, cannot be considered truly PES. In addition, many relevant agricultural practices are currently ignored by the CAP. For example, we showed that *grazing* practices is useful for wildfire prevention, which increment in Spain is one of the biggest socio-ecological problems in the last few decades (Ruiz-Mirazo, 2011). However, CAP direct payments penalize the use of trees and shrubs on pastures as they are considered a sign of abandonment or of non-productive land (Beaufoy et al., 2015).

4.3. Limitations and further research

Our work presents a number of limitations that also indicate research gaps. First, we used an expert-based assessment to quantify the benefits of different agricultural practices on ES delivery. However, further research on the biophysical effects of different practices and management regimes on ES would make the PES more sound. In addition, objective specifications for the "optimal" management regimes are required at the farm level, e.g., the optimal stocking rate should be tailored to very specific local circumstances. Second, despite ES delivery is affected by a wide range of agricultural practices, the inclusion of a high number of practices in the PES system may compromise its operability (Jónsson et al., 2016). It could be advisable to reduce or customize the practices to be included in particular policy settings, although this may affect slightly the outcome in terms of ES delivery. Third, we need to test the acceptance of the PES system by its main users, farmers and policy makers, as well as incorporate their viewpoints. Finally, we argue that technical advice to accompany farmers in changing their practices, the identification of simple and responsive agri-environmental indicators, and adequate systems of control are still needed to ensure the expected outcomes.

5. Conclusion

Agricultural practices may contribute to one or multiple ES, regardless the policy objectives. Promoting particular practices that have a strong influence on a single ES is advisable when this particular ES is the only target. However, when considering multiple ES, several practices become more important because of their multifunctional role, i.e. deliver ES in bundles. The quantification of the multiple effects of agricultural practices on ES is crucial in management-based PES; this can be rather straightforward following similar research approaches (e.g. expert-based assessment) in other agroecosystems.

The PES framework was able to reward farmers according to their objective contribution to diverse ES. It is generic, customizable according to particular agroecosystems and policy targets, and easy to use. The application of the PES framework in Mediterranean agroecosystem showed that the key agricultural practices delivering ES were those regarding grazing management, which should be prioritized in agri-environmental policy. The social-ecological systems approach that underpins the PES framework facilitates policy prioritization of one or multiple ES, and can help in guiding farmers to improve land management while obtaining fair economic reward from society.

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